Tangiers - Mediterranean harbor

Sylvie Bretelle, Bruno Demay, Agathe Touati, SAIPEM-SA

1. Introduction

On the south bank of the Gibraltar's Strait 40 km east of Tangiers city, the Morocco authorities have launched the construction of a new harbor, to favor the economical development of the North region and to improve the relationship between Morocco and the Euro-Mediterranean area. The main functions of the harbor are:

- Getting a part of the traffic of the containers transshipment
- Developing the traffic of trucks
- Rationalizing the affectation of the cereals traffic
- Serving the Tangiers hinterland with refined oil products
- Clearing the city of Tangiers, in order to turn its activity more to the tourism and make it as a pole of a cultural center.

The works are performed by a joint venture company (SRPTM) constituted by:

- BOUYGUES-TP
- SAIPEM-SA
- BYMARO (Morocco subsidiary company of Bouygues-BI)

2. Project description

2.1 General

This project, named "Tangiers - Mediterranean harbor ", was initiated to create a harbor in deep water, free zones of logistic, industrial, commercial and tourist facilities and infrastructures of motorways and railways connections.

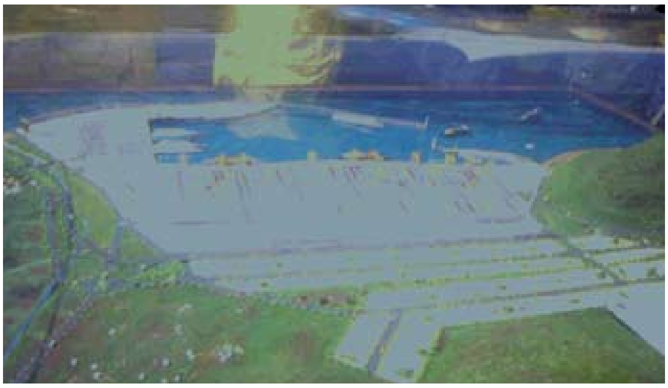

Figure 1: Tangiers-Mediterranen harbor project

The harbor of Tangiers-Mediterranean is protected by a main breakwater of 2,050 m length and a secondary breakwater of 570 m length. Both breakwaters are composed of one part of rubble mound and the other part of caissons depending upon the sea bed level. This breakwater will protect terminals to be erected later:

- A container terminal of 1,612 m length, offering a draught of 12 to 18 m and a reclamation area of 90 hectares.
- A 201 m length of quay, for feeders with a draught of 12 m.
- A cereal terminal with a 366 m length of quay, with a draught of 15 m.

Figure 2: Aerial view of the harbor

- A 225 m length utility quay, with a draught of 6 m.

2.2 Description of rubble mound

The rubble mound is realized with materials from quarry, placed by maritime or terrestrial way (Dumping from ship when water depth exceeds 10m, dumping from truck and pushed from land at shallow water depth). It is located in depths not exceeding 20 m. Its total length is around 1,000 m.

Figure 3: Detailed vew of breakwater

2.3 Description of breakwater

The Breakwater is constituted of 40 caissons based at level -20 m and placed one close to the other, along a total length of around 1,100 m. The horizontal dimensions of one caisson are 28x28 m and the height is 32 to 35 m. The caissons are longitudinally connected by means of concrete keys. The total concrete volume is 3,000 m3 per caisson. Caissons are filled with ballast in order to ensure installation and service stability. The weight of each unit is 7900 T.

2.4 Description of the caissons

The caissons are made of precast reinforced concrete and have 4 cells shape (sharmrock shape) filled with sand on a height of 23 m. Above this the superstructures are constructed constituted by three walls.

- A partially opened front wall (in order to reduce the swell energy),
- a rear wall as a screen to the swell
- a transverse wall to link the two previous walls.

Figure 4: Detail of caisson

General layout of the harbor is shown in the next picture, with caissons dike in the upper part of the drawing, and turning basin in the middle.

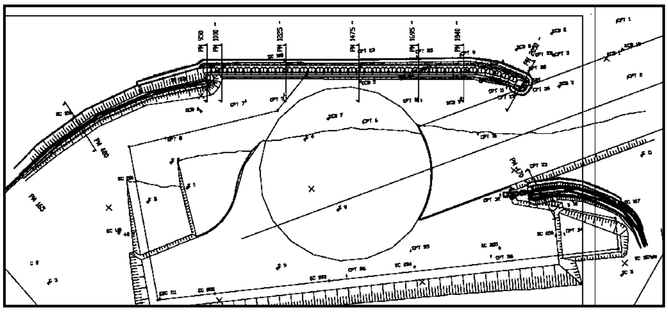

Figure 5: Harbor plan

Sol	Identification	MODELE	γ_{hum} (kN/m3)	Eel.moy. MPa	ν	E50 MPa	Eoed MPa	ϕ (°)	ψ	C' kPa	Cu kPa	Cc	Cs	e0
①	Sable silteux fin avec graviers occasionnels, debris coquillers et matiere organique	HSM	18	3	0.3	10	12.5	37	7	0	0			
②	Sable silteux fin-moyen, graveleux avec des poches d'argile silteuse sableuse	HSM	18	35	0.3	14	25	34	4	0	0			
③	Sable silteux fin-moyen avec graviers fins	HSM	18	10	0.3	29	40	36	6	0	0			
④	Argile silteuse / silt argileux	SSM	18.5		0.4			20		12	17	0.226	0.015	0.892
⑤	Argile legerement sableuse avec graviers et galets	SSM	20.6		0.35			20		18	18-31	0.106	0.009	0.573
⑥	Argile silteuse/sable fin tres silteux organique	SSM	19.9		0.4			20		28	40	0.250	0.043	0.823
⑦	Alternance d'argilite/gres - substratum	EPMC	23	400	0.2			20		80				

Table 1: Soil data

3. Geological context

According to detailed site investigation (CPT, boreholes, SPT, laboratory testing), several basement soils were identified. The geotechnical context is as follow:

Rubble mound breakwater:

Based on a bedrock composed of slightly to highly weathered siltstone/sandstone flysch (flysch is a thick deposit of distinctively interbedded sandstones and shales laid down by turbidity currents in a deep water marine environment during the early phases of orogenesis).

Caissons breakwater:

Based on soils (silts, sands and gravels), with foreseen settlements:

- FORMATION I: is mainly composed of sand,
- FORMATION II: Interbedded gravelly sand, clays and sandy gravel or clayey gravel.
- FORMATION III: Sandstone/siltstone substratum.

4. Simulation with Plaxis 2D

4.1 Soil Model

Plaxis was used to estimate the settlements (both global and differential) of the caissons. For this purpose, the different soil layers were considered with the following soil model:

Formation I: Hardening Soil Model, HSM in drained conditions (parameters defined from calibration on triaxial tests results). (soils 1-2-3 in table below)

Formation II: Soft Soil Model, SSM for clayey layers with available oedometer tests results to define C_c, C_s e0. Mohr Coulomb elasto-plastic model, EPMC for other gravely layers. (soils 4-5 in table below)

Formation III: Mohr Coulomb elasto-plastic model, EPMC with non porous conditions. Parameters are defined from in-situ tests and correlations.

One of the calculated cross section is shown here after, with a detailed table of the parameters used for the calculation.

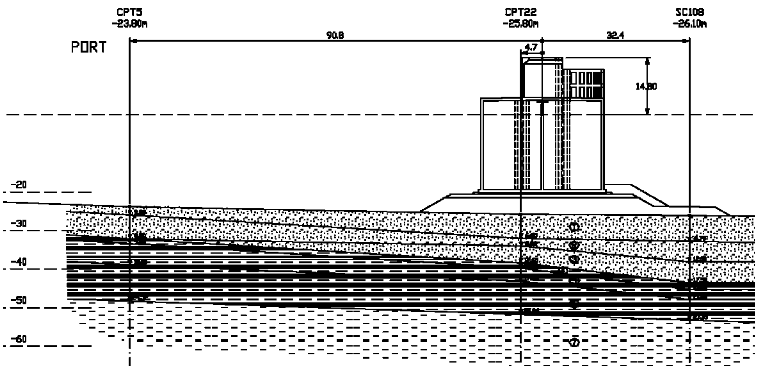

Figure 6: Cross section of caisson

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Continuation

4.2 Construction stages and estimated settlements

Construction stages are described here after for two sections part of the study.

Cereal quay area (PM 1000 et PM1225)

- Preparation of platform for caisson (between sea bed at -25m and caisson bottom at -20 m)
- Caisson installation and ballast
- Superstructure cast in place
- 2 month consolidation before backfilling behind the caissons
- Backfilling behind the caissons by 5 m height layers (in the model, to obtain a representative stress distribution), no consolidation allowed between backfilling stages
- Long term consolidation (up to full dissipation of excess pore pressure).

The Plaxis mesh is as follows:

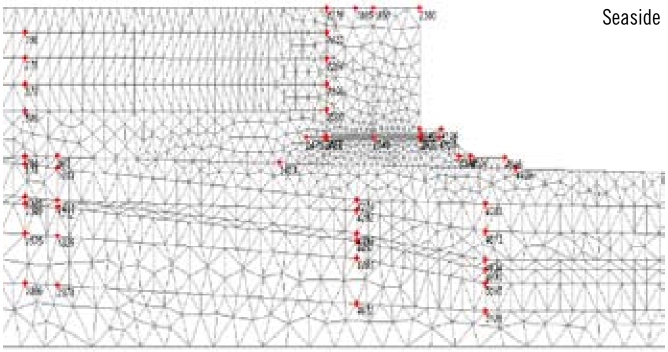

Figure 7: Plaxis model of cereal quay area

The table summarizes the main results from the calculation of caisson settlement (seaside, port side and on caisson axis).

	PM 1225		
	Port(cm)	Axis(cm)	Sea(cm)
Preparation of platform for caisson + 5 months consolidation	7.2	7.8	8.0
Caisson installation and ballast + 5 months consolidation	39.6	37.1	34.5
Superstructure cast in place + 2 months consolidation	2.1	2.4	2.8
Backfilling behind the caisson	7.6	5.9	4.2
Long term consolidation	11.1	10.0	8.9
Total caisson settlement	**60.5**	**55.4**	**50.3**

Table 2: Calculated displacements (quay)

Outside cereal quay area (PM 1475)

- Preparation of platform for caisson (between sea bed and caisson bottom at -20 m)
- Caisson installation and ballast
- Superstructure cast in place
- Long term consolidation (up to full dissipation of excess pore pressure).

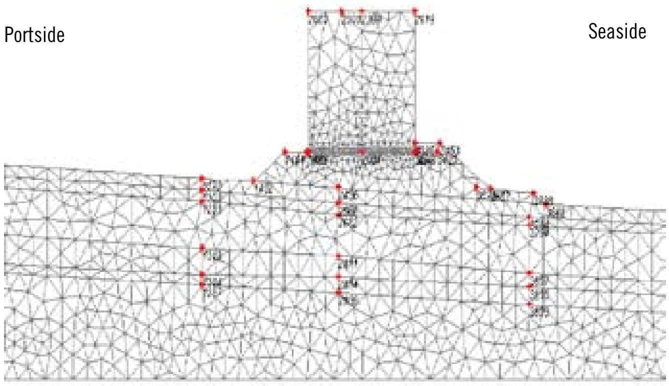

Figure 8: Plaxis model of caisson

The table summarizes the main results from the calculation of caisson settlement (seaside, port side and on caisson axis).

	PM 1475		
	Port(cm)	Axis(cm)	Sea(cm)
Preparation of platform for caisson + 5 months consolidation	7.2	7.8	8.0
Caisson installation and ballast + 5 months consolidation	39.6	37.1	34.5
Superstructure cast in place			
Total caisson settlement	**60.5**	**55.4**	**50.3**

Table 3: Calculated displacements (caisson)

5. Observed behavior during construction – comparison with Plaxis calculation

The compared observed behavior and calculated behavior are shown in this page, resulting in a good agreement. The first part of the curve correspond to the concrete caisson installation, and the observed step correspond to the ballast installed in the caisson.

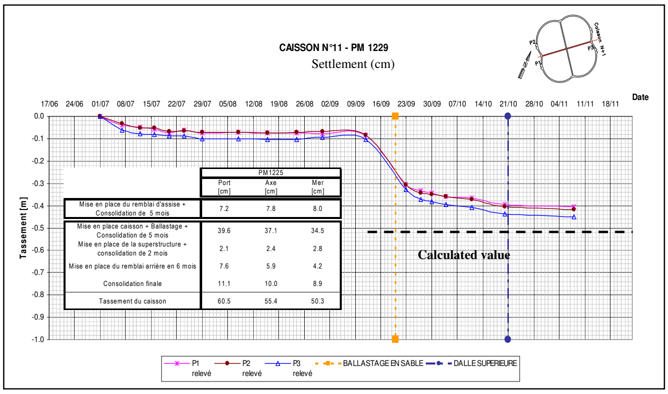

Figure 9: Observed vs calculated settlements

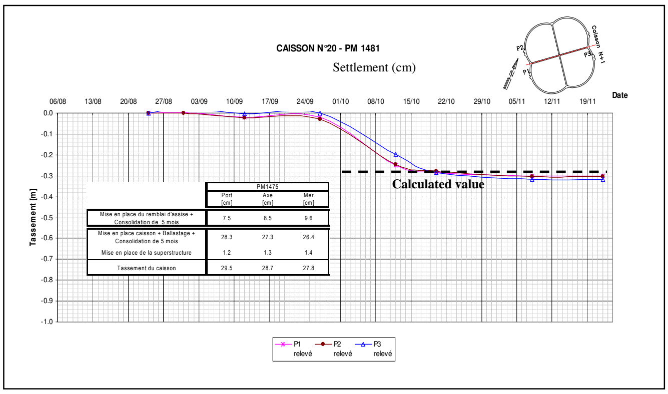

Figure 10: Observed vs calculated settlements

6. Dynamic simulation

A dynamic soil structure interaction was performed in order to confirm the validity of pseudo static calculation and to quantify settlements and rotations of caissons during seismic event. In addition, the pore pressure increase will be considered with regard to the liquefaction phenomena.

Main data considered for dynamic simulation are:

- Soil conditions / substratum position as shown in next picture
- Dynamic modulus (6 times static modulus) as laboratory tests shows a ratio between 5 and 8

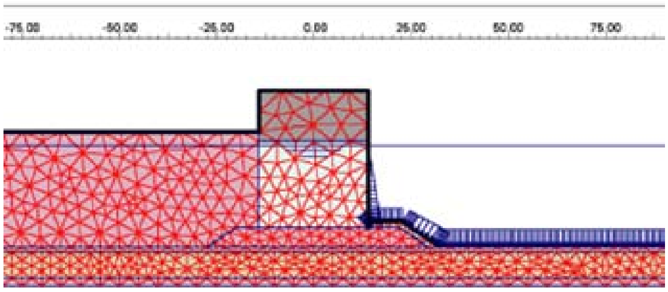

Figure 11: Plaxis model

Seismic signal: defined from existing seismic data to represent as much as possible the frequency content of most probable seism.

- Kocaeli (distant) Mw 8.5 a_{max} 0.093g
- Umbria (close) Mw 4.7 a_{max} 0.24g
- Signal imposed at rock substratum level.
- Dilatancy sensitivity analysis

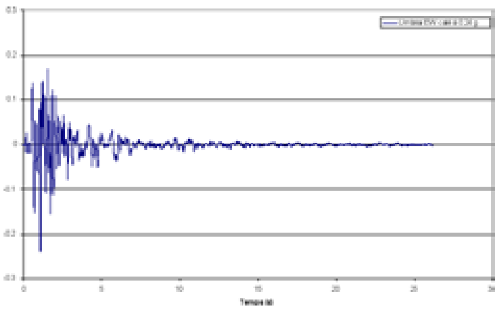

Figure 12: Typical short duration seismic event

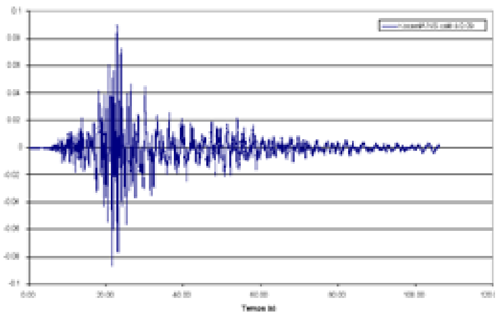

Figure 13: Typical long duration seismic event

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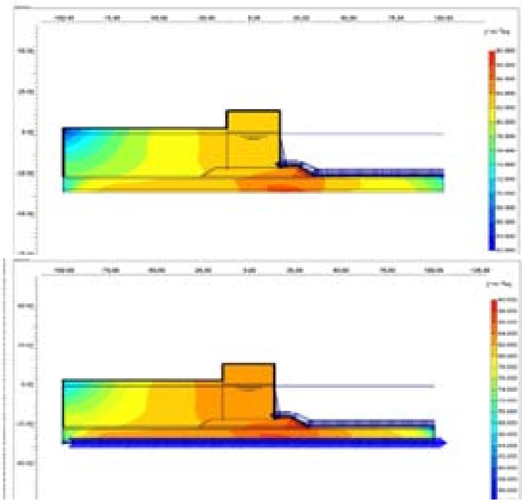
The dilatancy angle has an influence on the volume change of soil due to shear.
For static analysis, the retained dilatancy angle value was $0° < \psi < 0.5°$ allowing pore pressure generation during construction loading. This choice gives a proper correlation of observed and calculated settlement.

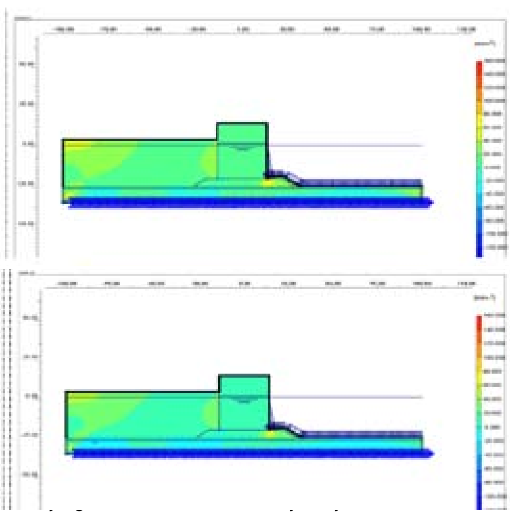
For sensitivity purpose, values of $5° < \psi < 10°$ ($\psi = \varphi - 30°$, correspond to the usual value) were compared to the case with $\psi = 1°$ (correspond to the value retained for static calculation).

The results show similar displacements.



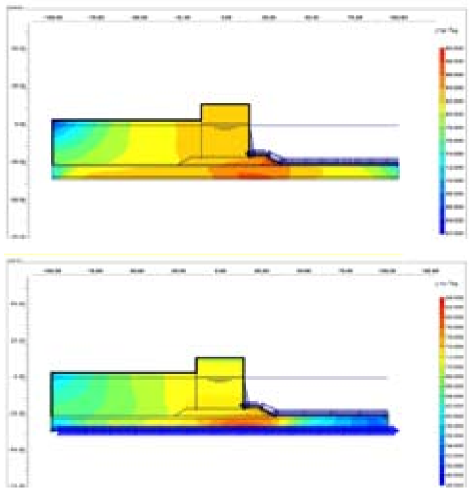
$\Psi = \varphi - 30°$ ↑
$\Psi = 1°$ ↓

The results show similar excess pore pressure.

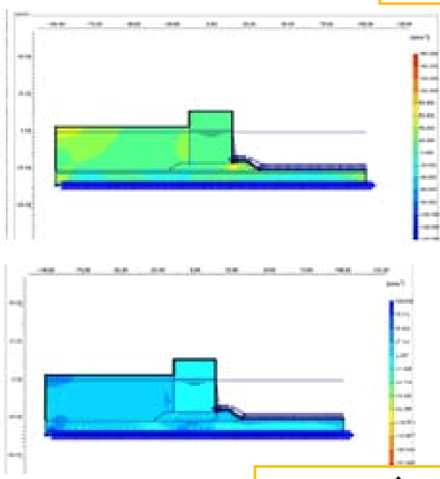


$\Psi = \varphi - 30°$ ↑
$\Psi = 1°$ ↓

$\alpha_R = \beta_R = 0.01$ (default values) and $\alpha_R = \beta_R = 0.03$ are considered for sensitivity analysis (proposed value in different reference sources).



α and β = 0.01 ↑ Dmax = 88 mm,
α and β = 0.03 ↓ Dmax = 83 mm,



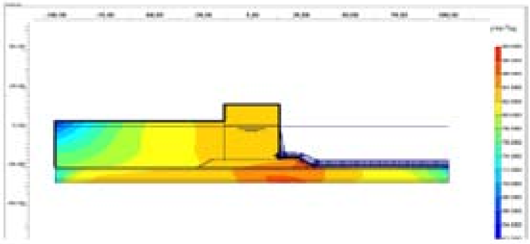
α and β = 0.01 ↑ extreme pore pressure 130 kPa
α and β = 0.03 ↓ extreme pore pressure 316 kPa

- Number of step sensitivity analysis

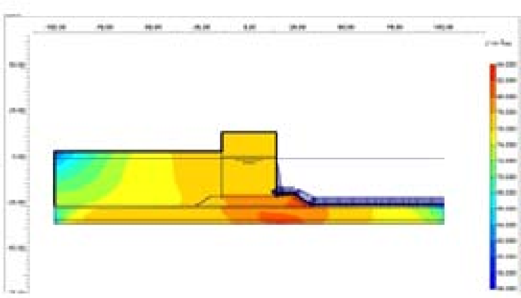
For the short duration seismic event, the application time was set to 10s and the time step to 0.2s (or 500 steps) or 0.01s (or 1000 steps for sensitivity analysis).

The used time step shall be lower than critical time step. The critical time step is a function of element size, shear moduli, and volumic weight of soils.

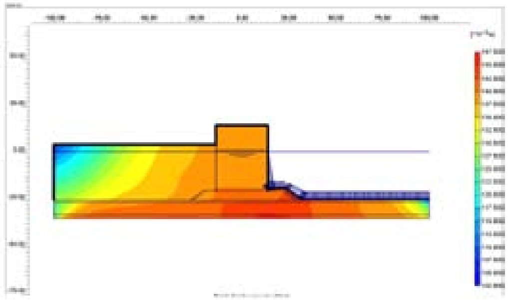
The calculation was performed with 500, 700 and 1000 steps in order to control the critical step number. Results shown are displacements.



Nb step = 1000 ↑ dmax =88 mm



Nb step = 700 ↑ dmax =82 mm



Nb step = 500 ↑ dmax =147 mm

The results are very similar for 700 to 1000 steps, whereas the results change dramatically for 500 steps. For 500 steps, the time step is probably lower than critical time step.

7. Results of the Plaxis dynamic analysis

The main results of this Plaxis dynamic analysis are:

- An accurate choice of the parameters is required (seismic signal, soil models and parameters) with dedicated soil investigation (both in situ and in laboratory), and seismic study,
- Precise answers are found related to amplification or attenuation of the seismic signal between substratum and structure,
- Localization of the higher pore pressure increase (zone of possible liquefaction),
- Quantification of the residual displacements after seism.

Some sensitivity analysis on different parameters help to define specific parameters for the dynamic model such as time steps, Rayleigh parameters and dilatancy.